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INVESTIGATION OF ALTERNATIVES TO EXOTHERMIC WELDING OF COPPER C--ETC(U)
JAN 81 S A WAGNER
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AIR FORCE COMMUNICATIONS COMMAND

(14) 1842 EEG/EEIC-TR-81-7

(9) Final rept. May-Dec 80.

DTIC

(10) Stuart A. Wag AFCC Technical Report

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# Investigation of Alternatives to Exothermic Welding of Copper Conductors to Ground Rods

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Base Communications Systems Branch
1842 Electronics Engineering Group (AFCC)
Scott Air Force Base, Illinois

(11) 15 January 1981

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|---|---|---|
| 1. REPORT NUMBER<br>1842 EEG/EEIC TR 80-11 | 2. GOVT ACCESSION NO.<br>AD-A097 728 | 3. RECIPIENT'S CATALOG NUMBER |
| 4. TITLE (and Subtitle)<br>Investigation of Alternatives to Exothermic Welding of Copper Conductors to Ground Rods | | 5. TYPE OF REPORT & PERIOD COVERED<br>Final May - December 1980<br>6. PERFORMING ORG. REPORT NUMBER |
| 7. AUTHOR(s)<br>Stuart A Wagner | | 8. CONTRACT OR GRANT NUMBER(s) |
| 9. PERFORMING ORGANIZATION NAME AND ADDRESS<br>1842 EEG/EEIC<br>Scott AFB IL 62225 | | 10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS |
| 11. CONTROLLING OFFICE NAME AND ADDRESS<br>1842 EEG/EEIS<br>Scott AFB IL 62225 | | 12. REPORT DATE<br>15 January 1981<br>13. NUMBER OF PAGES<br>12 |
| 14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office) | | 15. SECURITY CLASS. (of this report)<br>Unclassified<br>15a. DECLASSIFICATION DOWNGRADING SCHEDULE |

16. DISTRIBUTION STATEMENT (of this Report)

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17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Exothermic welding, ground rods, clamps - ground rod, lightning strike testing.

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)


Four types of conductor to ground rod attachments were subjected to accelerated corrosion exposure and subsequent low current, high current, and simulated ligtning strike tests. All samples passed all tests. This testing indicates that presently imposed restrictions on use of other than exothermic bonds for below grade use are unnecessary.


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This report has been reviewed and is approved for publication and distribution.

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## SUMMARY

Four devices used to bond copper conductors to ground rods were evaluated. Results indicate that exothermic welds, currently required for below grade use, can be replaced with simpler, less hazardous bonds. The inclusion of names of any specific commercial product, commodity or service in this publication is for information only and does not imply endorsement by the U.S. Air Force.

## ACKNOWLEDGEMENT

We gratefully acknowledge the personnel and facilities support given by:

Atmospheric Electricity Hazards Group
Vehicle Equipment Division
Air Force Wright Aeronautical Laboratories (AFSC)
Wright-Patterson Air Force Base, Ohio

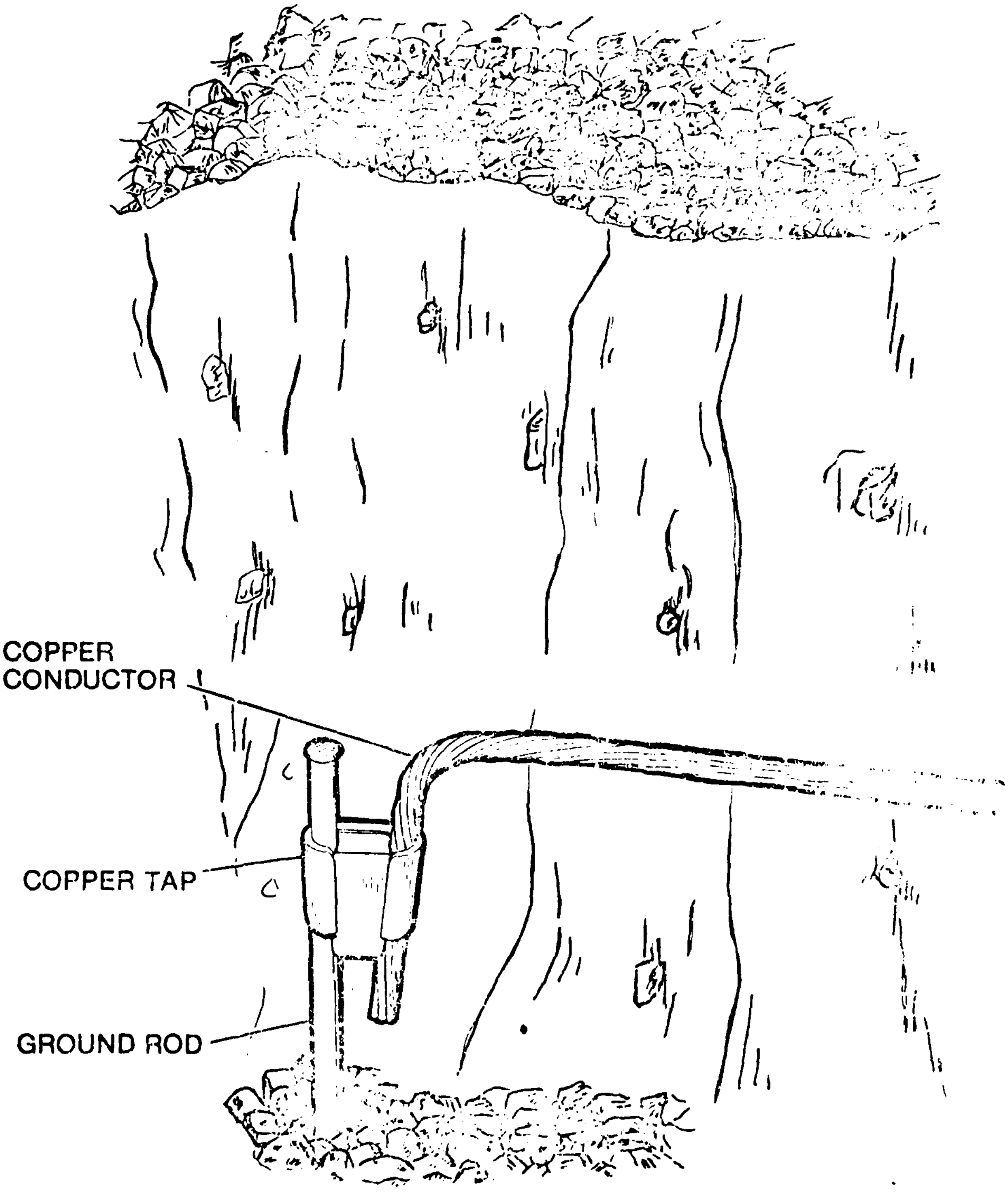



FIGURE 1. AMP COMPRESSION CLAMP

## 1.0 INTRODUCTION.

1.1 Participants at an Installation Technology Seminar, held 10 - 12 October 1979 at Scott AFB, Illinois, discussed methods of reducing on-site time requirements for AFCC Installation Teams. One recommendation was to investigate alternatives to exothermic welding, a currently approved method of bonding copper conductors to ground rods in buried or concealed locations. Objections to exothermic welding were itemized as:

a. Use ranges from difficult to impossible during wet and/or windy weather.

b. Severe burns, resulting in lost time, have occurred as result of the extreme heat generated during and immediately following the welding operation.

c. Noxious fumes given off during the welding process discourage use in confined locations.

1.2 One specific product was recommended for evaulation as an alternative, a compression bonding technique using a powder actuated charge developed by the AMP Corporation. The AMP clamp is illustrated in Figure 1.

1.3 The Installation Technology Unit of the 1842 EEG accepted the evaluation task.

2.0 PROCEDURE. It was decided that a more thorough evaluation of the problem should include testing of currently used ground clamps as well as the AMP and exothermic weld methods. Therefore, clamps manufactured by A. B. Chance and Burndy Manufacturing Co. were obtained through normal supply channels and were used as test samples.

2.1 Evaluation Phases. The evaluation consisted of the following discrete phases:

a. Evaluation of the AMP product and associated tooling

b. Accelerated corrosion exposure

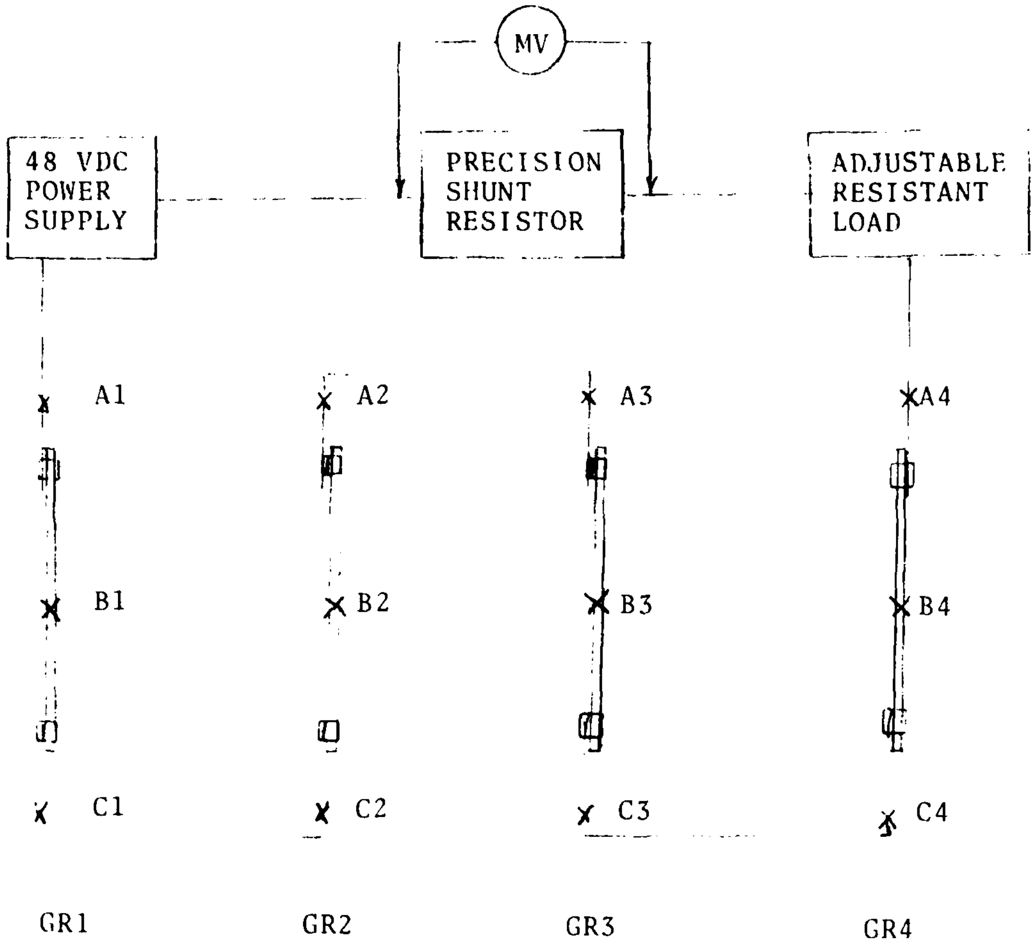
c. Low current electrical test

d. High current electrical test

e. Simulated lightning strike test

2.1.1 Evaluation of the AMP Product and Associated Tooling.

2.1.1.1 Determining Training Requirements. Arrangements were made to have AMP Corporation personnel demonstrate their compression clamp, associated tooling and the techniques necessary to accomplish the bonding operation. After the demonstration, the manufacturer loaned the tooling and sufficient clamps to USAF so that we could determine the amount of time required to train people in the use of the tools and techniques. Four people, ranging from basic airmen to GS-9 technician levels, were selected for participation; the only prerequisite was complete unfamiliarity with the product. All four participants attained proficiency after a simple narrative walk through, followed by "hands-on" use of the equipment. The entire training procedure took less than 30 minutes.




MV - Millivolt meter, Fluke Electronics, Model 8040A
A1,A2,A3,A4 - Test points approx. 3 inches from bond.
B1,B2,B3,B4 - Test points at mid point of 24 inch ground rod (GR).
C1,C2,C3,C4 - Test points approx. 3 inches from bond.
GR1- Burndy Corp. P/N 250-8 mounted each end.
GR2 - AMP Corp. P/N 3-275187-1 mounted each end.
GR3 - Cadweld P/N GR1-1616 mounted each end.
GR4 - Standard clamp mounted each end.

NOTE: ALL CIRCUIT WIRING IS AWG 4 STRANDED COPPER WIRE.

FIGURE 2. TEST SET-UP (CORROSION EFFECTS)

2.1.1.2 Surveying Industry Usage. Six Power and Light (P & L) companies using fossil fuel and two P & L's having nuclear power plants under construction were contacted. All P & L personnel agreed with the manufacturer's claim that in a conductor-to-conductor bond, as when making up a ground grid, the compression clamp readily deformed and reshaped the conductors to conform to the shape of the clamp/wedge combination, thus insuring an excellent conductor-to-conductor bond. However, all of the fossil fuel P & L's expressed reservations about the effectiveness and economics of conductor-to-ground rod bonds, due to the minimal copper coating on contemporary production ground rods. Five of the six relied on exothermic welding and the sixth used a less expensive, hydraulic actuated compression bond. One of the nuclear power plants is using the AMP product throughout its system, including rod-to-conductor bonds. The second plant, using compression clamps in their ground grids and exothermic welds on rod-to-conductor bonds, stated that had not a buy already been made for exothermic weld products, they would have gone with the AMP product for rod-to-conductor bonds.

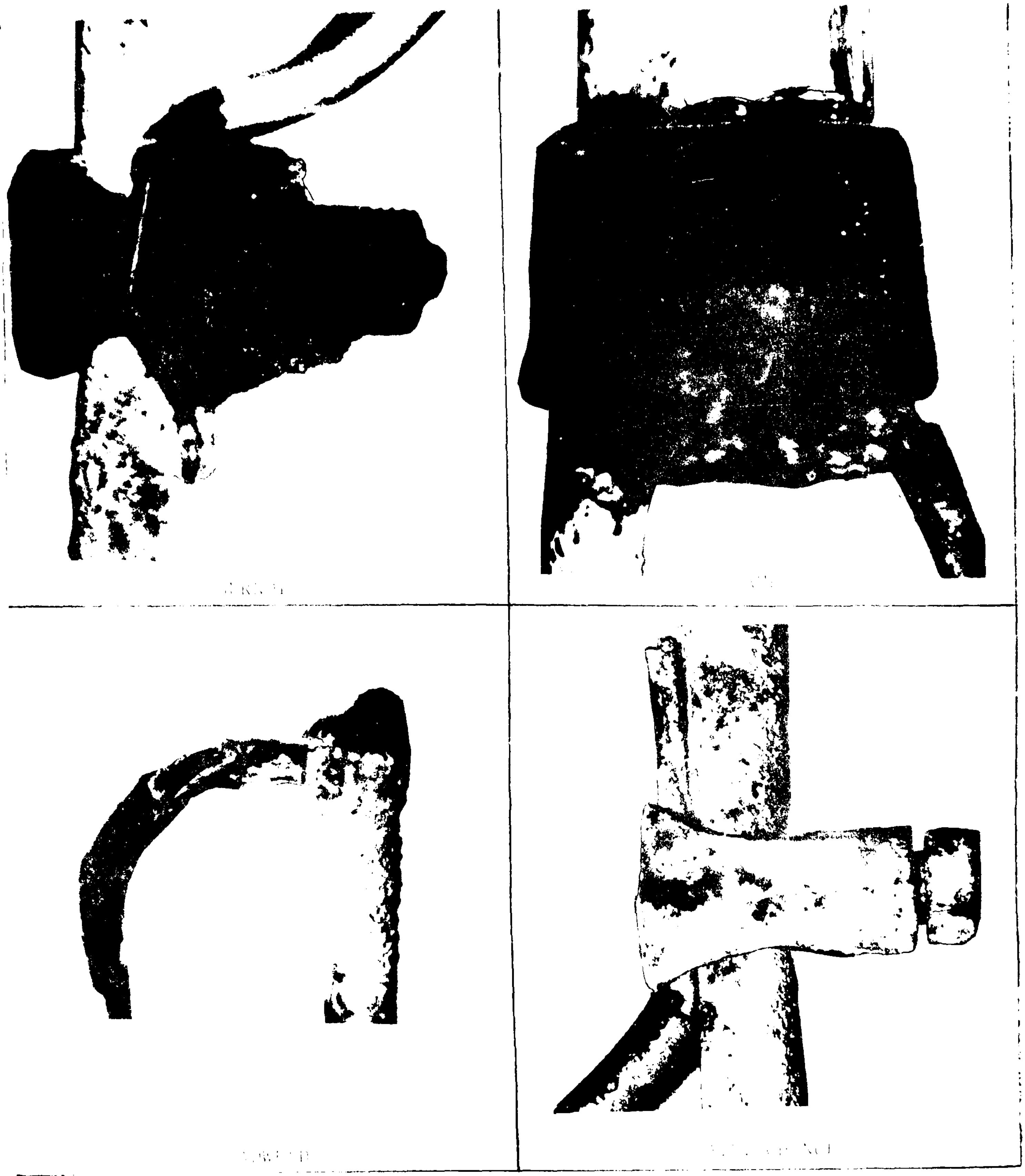
2.1.1.3 Evaluating Mechanical Design. An analysis of the mechanical design of the AMP tool emphasized that, although rugged in construction, the tool had several potential faults. Most of these were minor in nature and were concerned with maintenance and repair aspects. One potential safety hazard was noted; it seemed a craftsperson could be severely burned when hot gases were vented from the combustion chamber. Physical testing of the tool confirmed that improper handling could result in venting the gases in a manner that could cause injury. The eight industry sources were queried about injuries associated with using the tool. One organization informally reported experiencing a serious accident caused by hot gas venting into a craftsperson's eye. The company continues to use this system, and feels comfortable in comparing the great number of successful bonds to this one incident. They emphasized that the accident resulted from human error, not from tool malfunction or breakage.

2.1.2 Accelerated Corrosion Exposure.

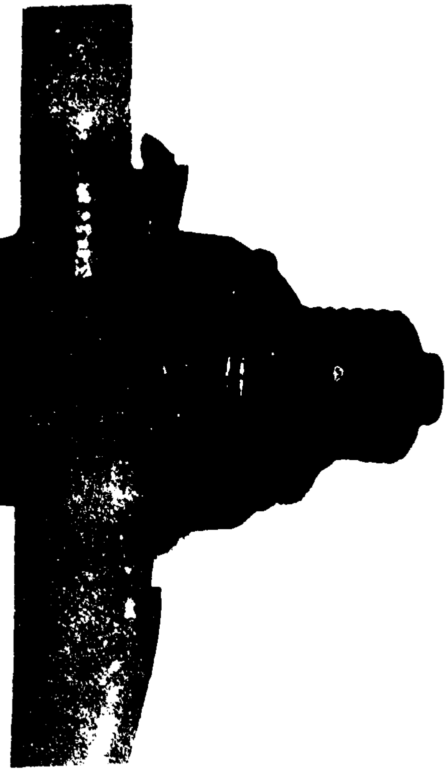
2.1.2.1 Two of the AMP clamps, two exothermically welded joints, and two each of two other in-stock clamps were selected for accelerated corrosion testing. The clamps were mounted on sections of ground rod approximately 24 inches long. Figure 2 shows the test set-up and identifies the clamps. One of each type clamp was grease coated to reduce corrosion effects, the other was left untreated. The ground rod sections were series connected, fastened to a board and placed in a tightly covered steel drum. The covered drum was placed to receive maximum sunlight, insuring that the samples were subjected to the greatest possible amount of naturally generated heat.

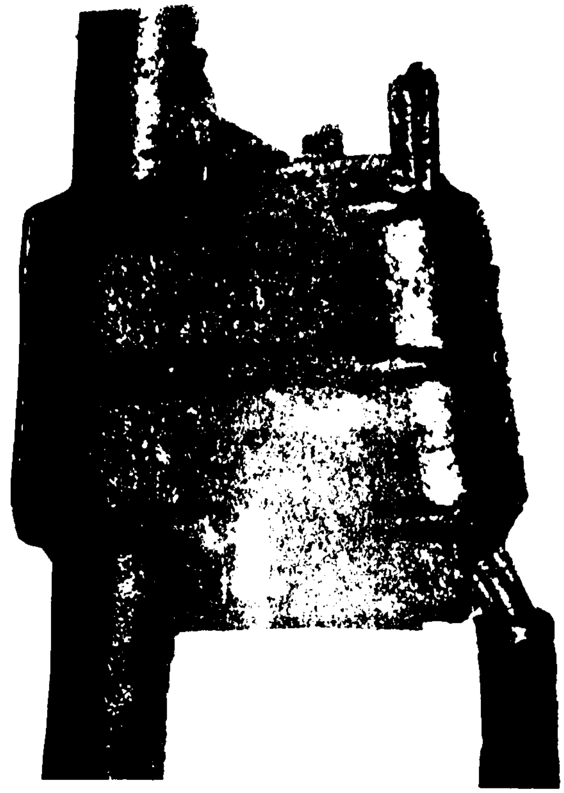
2.1.2.2 Twice daily, except weekends, the specimens were fine-sprayed with a solution made from one gallon of water and one pound of common table salt. Twice weekly the specimens were subjected to very hot sulphur dioxide and nitrous oxide fumes generated by a standard fumigator flare. The tight fitting cover contained the fumes within the drum, allowing the corrosive atmosphere to remain until the cover was removed to take readings or to apply the salt spray. This time ranged between 14 and 90 hours after fuming.

2.1.2.3 The test specimens showed significant corrosion on the untreated surfaces after 5 days of exposure. Corrosion products, primarily copper sulphates on copper surfaces and iron oxides on the steel rod tips, uniformly increased throughout the 39 day period of exposure; at which time a condition of excessively heavy corrosion existed on all untreated surfaces. As expected, the protected surfaces showed only minimal corrosion. The most severely corroded specimen, the untreated end mounted exothermic weld, had both copper sulphate and iron oxide deposits. Figures 3 and 4 show the test specimens after corrosion exposure.



CORRODED SPECIMENS





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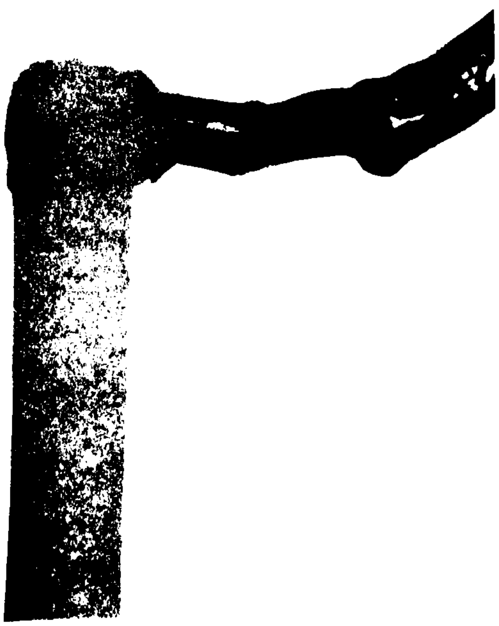
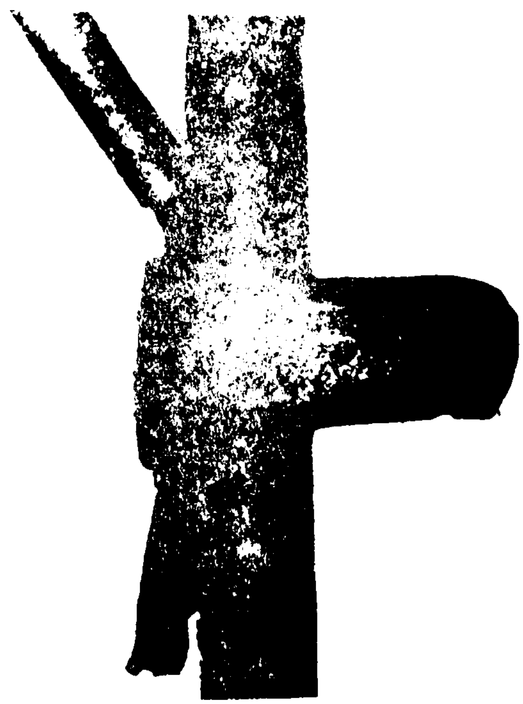




CADWELD

FIGURE 4. CORRODED SPECIMENS (GREASE)

| GROUND ROD CLAMP TEST MAY-JUNE 1980 | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| SALT SPRAY PLUS SULPHER DIOXIDE AND NITROUS OXIDE FUMES<br>MILLIVOLT DROP ACROSS CLAMPS | | | | | | | | | |
| $I_T$ | CLAMP / DATE | BURNDY 1 | BURNDY 2 | AMP 3 | AMP 4 | CADWELD 5 | CADWELD 6 | STANDARD 7 | STANDARD 8 |
| 20 | 8 May | 2.3 | 2.7 | 2.1 | 2.3 | 2.9 | 2.3 | 2.4 | 2.5 |
| 20 | 12 | 2.4 | 3.0 | 2.2 | 2.5 | 3.2 | 2.6 | 2.5 | 2.1 |
| 20 | 14 | 2.6 | 2.7 | 2.3 | 2.7 | 2.6 | 2.8 | 2.1 | 2.5 |
| 20 | 19 | 2.5 | 2.7 | 2.3 | 2.4 | 3.7 | 2.3 | 2.5 | 2.5 |
| 20 | 21 | 3.2 | 3.5 | 3.0 | 3.4 | 4.5 | 4.3 | 3.2 | 3.5 |
| 20 | 23 | 3.2 | 3.6 | 3.6 | 3.2 | 4.7 | 4.3 | 3.4 | 3.4 |
| 20 | 27 | 3.7 | 3.5 | 3.6 | 3.1 | 4.8 | 4.4 | 3.6 | 3.4 |
| 20 | 29 | 3.5 | 3.6 | 3.4 | 3.3 | 4.7 | 4.6 | 3.0 | 3.5 |
| 20 | 2 June | 3.6 | 3.5 | 3.2 | 3.5 | 4.6 | 4.5 | 3.1 | 3.9 |
| 20 | 4 | 3.4 | 3.6 | 3.4 | 3.2 | 4.6 | 4.5 | 3.1 | 3.7 |
| 20 | 6 | 3.3 | 3.7 | 3.3 | 3.4 | 4.8 | 4.6 | 3.1 | 4.1 |
| 20 | 9 | 3.6 | 3.4 | 3.4 | 3.2 | 4.8 | 4.2 | 3.4 | 3.5 |
| 20 | 11 | 3.3 | 3.6 | 3.3 | 3.3 | 4.7 | 4.3 | 3.3 | 3.6 |
| 20 | 14 | 3.2 | 3.6 | 3.4 | 3.1 | 4.9 | 4.3 | 3.2 | 3.6 |
| 20 | 16 | 3.4 | 3.9 | 3.6 | 3.5 | 5.2 | 4.6 | 3.5 | 3.9 |
| 50 | 19 | 9.4 | 10.3 | 9.0 | 8.9 | 12.9 | 12.8 | 9.3 | 10.1 |
| 65 | 19 | 11.8 | 13.5 | 12.3 | 12.2 | 17.6 | 16.7 | 12.7 | 13.7 |
| 75 | 19 | 13.7 | 15.9 | 14.7 | 14.4 | 20.9 | 19.4 | 15.5 | 15.9 |
| 100 | 19 | 17.7 | 20.7 | 18.5 | 18.7 | 27.2 | 26.4 | 19.1 | 20.1 |

NOTE: $I_T$ IS THE TOTAL CIRCUIT CURRENT IN AMPERES

TABLE 1
VOLTAGE DROP MEASUREMENTS
ACROSS TEST CLAMPS

2.1.3 Low Current Electrical Test. Table 1 notes the current through the test circuit on each test date and records the voltage drop (in millivolts) across each of the clamps on that date. The initial (8 May) reading was taken prior to corrosion exposure and represents the combined resistance of 3 inches of #4 AWG stranded copper wire, the clamp under test, and approximately 12 inches of copper coated ground rod. Clamps 1, 3, 5 and 7 are the untreated specimens, and clamps 2, 4, 6 and 8 are the grease covered ones. Tests were made using the following routine:

a. Remove samples from the drum and connect into the test set up, per Figure 2.

b. Obtain a 20 ampere current flow through the circuit by applying power and adjusting the load until a 95 millivolt reading is shown across the precision shunt resistor.

c. Measure and record readings between test points across each clamp.

d. Cut off power, remove samples and return them to the drum. Apply salt spray and, if applicable, corrosive fumes.

2.1.4 High Current Electrical Test. On 19 June 1980 the samples were tested using a 50 volt, 100 ampere regulated power supply source. The last four entries in Table 1 show voltage drop readings across the test specimens for current flows of 50, 65, 75 and 100 amperes. All test specimens remained cool to the touch during the tests; the #4 AWG wire temperature rose approximately 20$^{\circ}$ F during the 10 minute 100 ampere test.

2.1.5 Simulated Lightning Strike Test.

2.1.5.1 Personnel at the Atmospheric Electricity Hazards Group of the Air Force Wright Aeronautical Laboratories (AFWAL/FIESL) at Wright-Patterson Air Force Base set up and conducted simulated lightning strike testing.

2.1.5.2 Twelve samples of non-corroded and corroded specimens, each consisting of a length of #4 copper wire attached to a 5/8 inch ground rod section by means of the various clamps, were submitted to AFWAL/FIESL for destructive lightning tests. Figure 5 shows the test set up schematic.

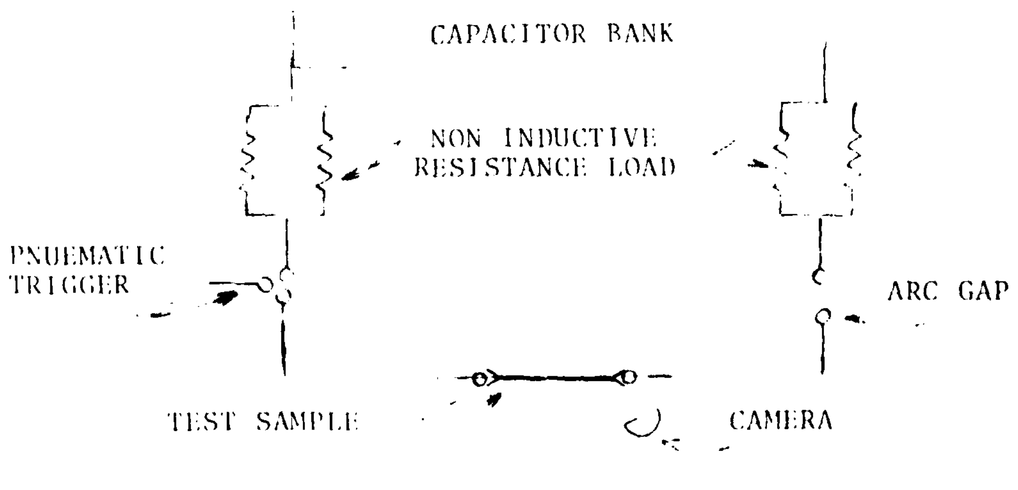



FIGURE 5. TEST SET UP (SIMULATED LIGHTNING)

2.1.5.3 In the first test series, the load resistance was fixed at 200 milliohms and all samples were subjected to simulated lightning strikes up to a maximum strike level of 75,000 volts and 120,000 amperes. None of the 12 samples, corroded or non-corroded, failed at any strike level. A reproduction of the recorded waveform is shown in Figure 6.

2.1.5.4 In the second test series, the load resistance was reduced to 40 milliohms and simulated strikes up to a maximum level of 90,000 volts and 190,000 amps were applied to 11 of the samples without failure. When maximum strike was applied to the 11th sample, all four load resistors exploded, although no arcing occurred at the clamped connection. Three 1/2 inch solid aluminum rods and one load resistor were used in testing the twelfth sample. The sample assembly did not arc but the single load resistor exploded. A reproduction of the recorded waveform is shown in Figure 7.

FIGURE 6

LOW ENERGY WAVEFORM

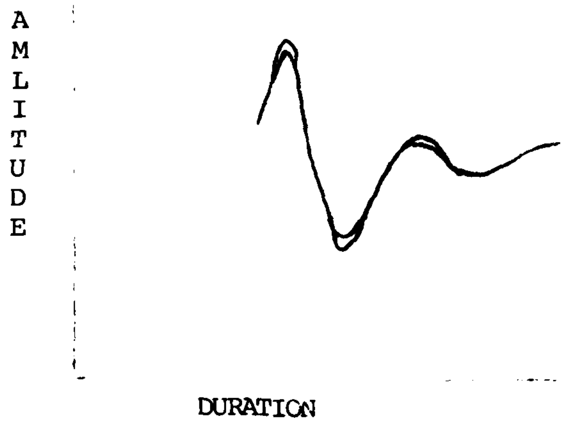
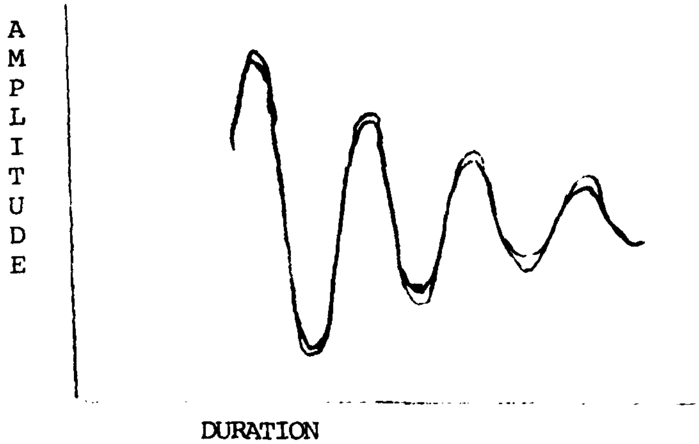



FIGURE 7

HIGH ENERGY WAVEFORM




2.1.5.5 In the third test series, the corroded A.B. Chance assembly was subjected to 10 consecutive strikes at the 75,000 volt - 120,000 ampere level. No arcing or other signs of failure occurred. None of the remaining samples were subjected to consecutive strikes since their construction and mass was judged superior to the tested sample. This completed the simulated lightning strike testing.

2.1.5.6 During the post test discussion, test personnel, including acknowledged experts in high-voltage high-energy electromagnetics, emphasized the following points:

a. The testing subjected the samples to the equivalent of a direct hit by "typical" lightning strikes.

b. Based on the testing, it is apparent that standard ground rod clamps, properly installed, will maintain the integrity of the ground path under direct strike conditions.

## 3.0 FINDINGS AND RECOMMENDATIONS.

### 3.1 AMP Compression Clamp.

3.1 Finding: As noted in paragraph 1.2, the primary purpose of this evaluation was to determine if the AMP compression clamp should be adopted for ground rod to conductor bonding. It was found that:

a. Personnel could be readily trained to use the AMP system.

b. Although P & L's in general agreed that the AMP clamp was very effective for conductor-to-conductor bonds, none of the operating companies presently used this system for conductor-to-ground rod bonding.

c. The mechanical design of the tool had potential faults that might affect maintenance and repair. Although minor in nature, they could cause work stoppage due to tool non-availability.

3.1.2 Recommendation. The AMP system will not be recommended for general U.S. Air Force adoption due to the need for special tooling, and beceause subsequent findings document the effectiveness of less sophisticated bonding devices.

### 3.2 High Current Test.

3.2.1 Finding. After build-up of heavy corrosion products, all test specimens were capable of carrying 100 ampere currents without a noticeable rise in resistance. This indicates that personnel and equipment protection is adequate for commonly occurring electrical leaks and shorts provided the associated earth ground is capable of dissipating the resultant currents.

3.2.2 Recommendation. Use of standard inventory ground clamps for personnel and equipment protection for commonly occuring electrical leaks and shorts should be encouraged. USAF Standard Installation Practices Technical Orders (SIPTOs) should be changed to include this finding.

### 3.3 Effects of Chemical Deterioration.

3.3.1 Finding. Chemical deterioration, caused by corrosive action, will probably be the ultimate cause of failure in an untreated conductor to ground rod bond. The failure will probably occur in the conductor at the point where it joins the clamp. This is based on the assumption that galvanic action will occur due to metallic dissimiliarities existing between the conductor, the clamp and the copper coating on the rod. The anticipated galvanic action, combined with the effects of corrosion, should make this the weakest point in the system. The protective coating applied to the treated bonds significantly reduced corrosion buildup and did not adversely affect the electrical bond. Use of an asphaltic protective coating, rather than grease, would probably have eliminated all corrosion, since the grease ran to some degree during periods of high heat exposure. It should be noted that grease, rather than asphalt, was used purposely since we anticipated a need to easily remove the protective coating for inspection of the bond.

3.3.2 Recommendation. The use of asphaltic based protective coatings on above and below grade bonds, and inaccessible bonds, should be reaffirmed and expanded upon. SIPTOs and applicable Military Specifications/Standards should be amended as necessary to implement this procedure.

3.4 Use of Exothermic Bonds.

3.4.1 Finding. Both the protected and unprotected exothermic bonds had the highest resistance initially and throughout the test period. Improper application of the unprotected bond resulted in formation of both copper sulphates and iron oxides at the tip of the ground rod. Since these bonds were accomplished by personnel having experience with this technique, it must be assumed that improper bonds of this type have occurred, and will continue to occur, under field conditions. The current carrying capacity of the improper bond was not adversely affected. The use of a protective coating, as noted above, should eliminate the corrosion products and insure the usefulness of the bond.

3.4.2 Recommendation. The exothermic welding process should not be mandatory for use in buried/concealed locations. USAF SIPTOs and applicable Military Specifications/Standards should be changed to acknowledge this.

3.5 Effects of Simulated Lightning Strikes.

3.5.1 Finding. Simulated lightning strikes up to a maximum strike level of 90,000 volts and 190,000 amperes were applied to all test specimens without adverse affect. It is apparent that standard ground rod clamps properly installed, will maintain the integrity of the ground path under direct strike conditions.

3.5.2 *Recommendation.* Use of standard inventory ground clamps should be encouraged. USAF SIPTOs should be changed to include this finding.

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